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AUGUST 1977
TECHNICAL REPORT NO. 189
CONTRACT NO. N00014-77-C-0186

PREPARED FOR:

NAVAL OCEAN RESEARCH AND DEVELOPMENT ACTIVITY
(NORDA)
CODE 500
BAY ST. LOUIS, MISSISSIPPI 39520

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A survey program was conducted to identify the Navy's oceanographic measurement needs which are not being met by currently available instrumentation. The scope of the survey, as dictated by funding limitations and a quick-response requirement, was limited to measurements needed to support ongoing Navy programs related to sensor and weapon systems as opposed to measurements

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20. ABSTRACT

needed for general oceanographic research. The survey also included a summary of the state-of-the-art capabilities of current oceanographic instrumentation. A number of instrumentation needs have been identified which are receiving inadequate attention and/or support.

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Section 1

INTRODUCTION

One of the tasks of the Exploratory Development Office, Code 500, of NORDA is the development of oceanographic instruments to meet Navy measurement needs for which instrumentation is not commercially available. In order to carry out this task effectively, it is necessary for NORDA to be familiar with: (1) ongoing programs in the Navy community which require measurement of oceanographic parameters, (2) the state-of-the-art in oceanographic instrumentation in order to identify measurement requirements which are not being met and (3) instrumentation R&D programs outside of NORDA in order to identify areas of need which are not being addressed or which require additional support. It was the purpose of the work reported on here to provide such information to NORDA through a survey of the Navy and oceanographic R&D community.

The approach to the survey consisted of two phases. The first phase was to review previous survey work on requirements vs state-of-the-art in marine instrumentation. This included looking at work done in both the military and civilian communities. This phase served to take advantage of previous survey work already performed, to avoid unnecessary duplication, and to better define the best approach to conducting the survey. The second phase combined a survey of the Navy's oceanographic measurement needs with a survey of development programs in those areas where instrumentation needs were identified. As will be discussed later, <u>the approach taken in the second phase was to concentrate on measurements needed to support ongoing system-related programs as opposed to measurements needed for general oceanographic research.</u>

Section 2 of this report summarizes the review of previous survey work and the conclusions reached on the approach to be taken in conducting the survey. Section 3 presents the results of the survey and Section 4 is a summary. Recommendations on types of instrumentation which are receiving inadequate attention or support are presented in Section 5.

Section 2

PREVIOUS SURVEYS OF REQUIREMENTS VS STATE-OF-THE-ART

2.1 OBJECTIVE AND APPROACH

The purpose of reviewing previous surveys was to take advantage of work already performed, to avoid unnecessary duplication, and to better define the scope of and approach to the survey work to be done. In addition, the most recent summary of the state-of-the-art in oceanographic measurement capabilities was to be updated, if necessary, to reflect recent improvements.

The review work was carried out by searching the open literature and technical reports and contacting knowledgeable people involved in oceanographic work in both the military and civilian communities. One of the problems initially encountered in the literature search was obtaining copies of many of the potentially relevant reports since many were not readily available from either a central source or from the source of origin. This problem was largely circumvented by locating personal copies in the Washington area and borrowing or browsing through them. The updating of the most recent state-of-the-art summary was done by contacting commercial manufacturers and sorting out the best available instruments.

2.2 RESULTS

A considerable number of both general and limited scope surveys, review articles and assessment reports have been published in the last decade or so. They cover the gamut in marine parameter measurements including the physical, chemical, biological and geological properties of rivers, lakes, estuaries, coastal waters and the deep ocean. These are listed in the Reference section in chronological order. Two of the most useful for an overview of the entire field of marine instrumentation are Ref. 4, "Ocean Instrumentation: Problems and Promise," from the IEEE Ocean '75 Conference and Ref. 6, "Ocean Instrumentation," which was prepared by NOAA for the

National Ocean Policy Study of the U.S. Senate. Probably the most comprehensive assessment study available was conducted for the U.S. Coast Guard by Texas Instruments in 1970 and is reported in Ref. 17. This includes a voluminous compilation of all commercially available oceanographic sensors and instruments with their specifications.

Based on articles and reports we were able to obtain, on browsing of other people's copies, and on personal discussions, a number of noteworthy observations were made:

- NOAA and the U.S. Coast Guard have recently solicited proposals for studies on marine instrumentation.[27, 28] The Coast Guard study is a summary and assessment of the state-of-the-art of all forms of underwater sensing. The NOAA study consists of three parts: (1) identifying marine data needs, (2) assessing the state-of-the art in marine instrumentation, and (3) comparing (1) and (2) to uncover technological deficiencies. The NOAA study is similar in nature to the present NORDA study, but the scope is to include the measurement needs of "government, academia and industry for marine environmental data." This is a big undertaking and should be a very useful product if a thorough job is done. The results of both of these studies should be quite useful to NORDA.

- Most requirement surveys have given only a single number or range of a number for a required capability. What is needed when one is dealing with more than one type of use and type of user is a histogram of requirement vs the number of users needing that requirement and the particular

use associated with the requirement. This is particularly important for cost-effectiveness considerations if a single instrument is to be developed for a variety of users. Figure 1 gives the type of information needed. This data was gathered during a recent questionnaire survey by NOAA's Office of Ocean Engineering of water quality measurement requirements[1]. Collecting this type of information requires care in the distribution of questionnaires to ensure a meaningful interpretation.

- Measurement capabilities are only one area of instrumentation characteristics which must be considered in the development or improvement of marine instrumentation. Characteristics may be conveniently grouped into three areas:

  1. performance characteristics
  2. operational characteristics
  3. logistics characteristics

  The first of these are the measurement capabilities of the instrument such as range, accuracy, resolution, time and frequency response, etc. Most requirement surveys have concentrated only on this area. The second are the operational limitations and conditions and involve considerations such as tow speed, sea state, in-situ capability, automation of data collection, real-time processing and ease of deployment. The development of expendable and air deployable instruments as well as benefits from size and weight reduction come under this category. Requirements on these characteristics

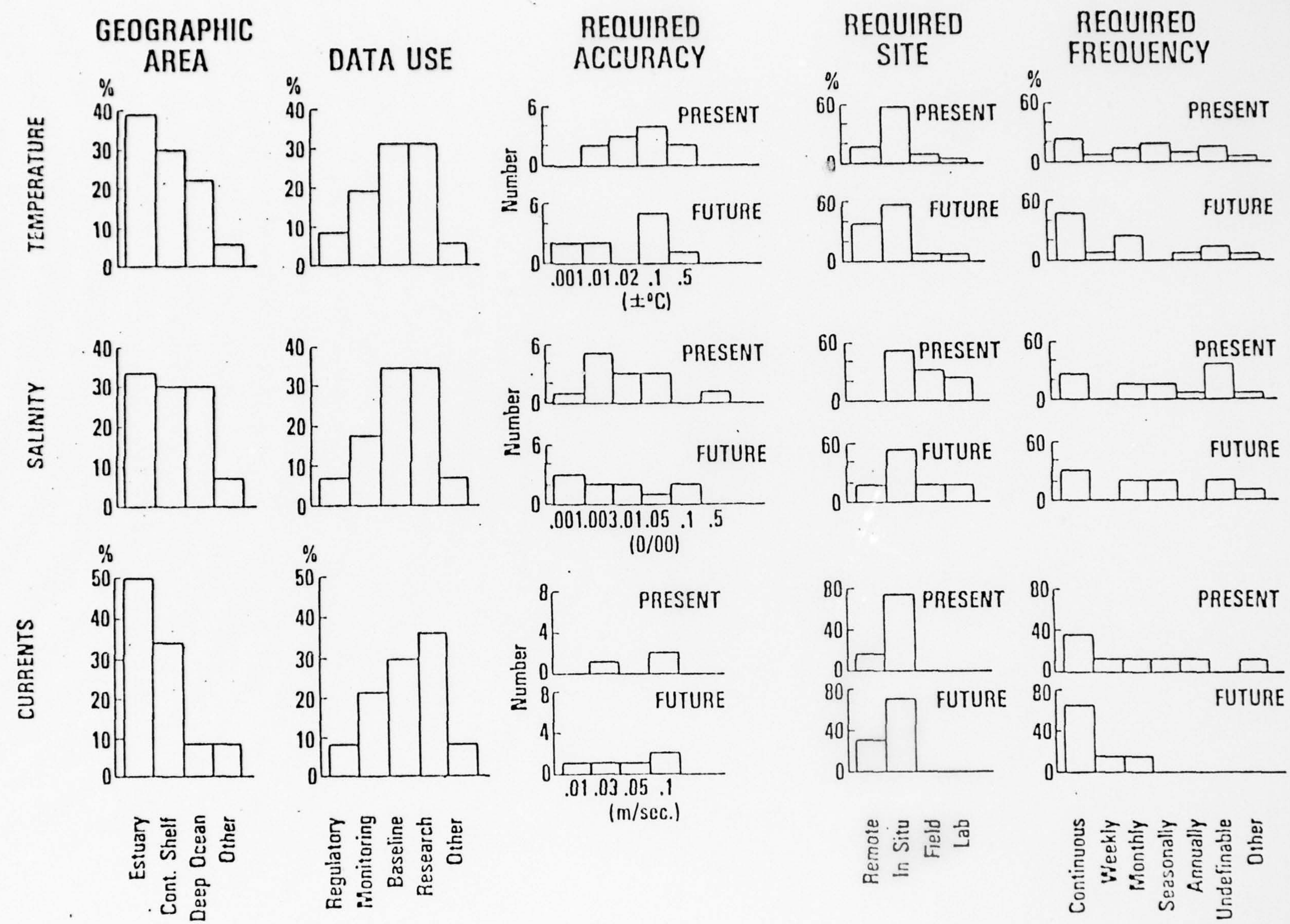

Figure 1. Preliminary Survey Results of Water Quality Measurement Requirements for Temperature, Salinity and Current (Reproduced with the permission of the Office of Ocean Engineering, NOAA)

are less well documented, probably because more subjectivity is involved. This area, however, presents the best opportunity for application of recent technology advances in areas such as fiber optic data transmission, microprocessors and Kevlar strengthened cables. The third area includes factors such as initial cost; ease and cost of maintenance, repair and calibration; auxiliary support equipment such as winches, cables; etc.

- Coastal zone measurements, especially by remote sensing techniques, are receiving considerable emphasis in the civilian field due to their relevance to pollution studies and the offshore oil and fishing industries. Shallow water bathymetry measurements from aircraft, in particular, have been of interest to NASA, NOAA and the Coast Guard in recent years and have application to Naval amphibious operations.

- An area that has been receiving considerable attention is remote sensing of ocean properties from satellites. Figure 2 taken from Ref. 6 shows various ocean properties measured by a number of different satellites. Aircraft measurements, while more versatile, have received much less attention. With the rapid survey capability afforded by aircraft, it would seem that instrumentation development in this area should receive more emphasis.

Figure 3 shows the results of a 1974 oceanographic instrument inventory survey by NOAA[6] and Fig. 4 shows 1975 oceanographic instrument development funding. The latter information would be much more useful if the funding were broken down into type of instrument, intended application,

SATELLITE	INSTRUMENT	SURFACE PARAMETER *MEASURED*	FORMAT/RANGE	ACCURACY	REMARKS
NOAA-3	SCANNING RADIOMETER (SR) VERY HIGH RES. RADIO METER (VHRR)	SEA SURFACE TEMPERATURE TEMPERATURE FIELD (GULF STREAM) POLLUTION MONITORING SEA ICE	DIGITAL/IMAGERY	SPATIAL – 8 km TEMP. – 1.2°C (rms) SPATIAL – 1 km	AVERAGED OVER 100 km^2 MULTIDAY COMPOSITE TO REMOVE CLOUDS
SMS/GOES	VISIBLE/IR SPINSCAN RADIOMETER (VISSR) DATA COLLECTION SYSTEM	SURFACE FEATURES SEA SURFACE TEMPERATURE BUOY/PLATFORM *INTERROGATION*	IMAGERY	SPATIAL < Vis – 1 km, IR – 8 km *TEMP. 1 – 2°C rms*	2 SATELLITES ATLANTIC/PACIFIC FULL EARTH DISC. EVERY 1/2 HOUR 10,000 DATA PLATFORM RELAY CAPABILITY
ERTS–1 ERTS–8	MULTISPECTRAL SCANNER (MSS) *DATA COLLECTION SYSTEM* RETURN BEAM VIDECON (RBV)	SURFACE FEATURES AND DISCONTINUITIES SEA ICE DISTRIBUTIONS AND PROPERTIES	SPECTRAL IMAGERY MSS 0.5 TO 0.6 μm, 16 TO 17 μm, 0.7 TO 0.8 μm, AND 0.3 TO 1.1 μm RBV 0.475 TO 0.515 μm, 0.580 TO 0.680 μm, AND 0.698 TO 0.330 μm ERTS–8 THERMAL 10.4 TO 12.5 μm	SPATIAL – 100 METERS	8 DAY REPEAT CYCLE SUN SYNCHRONOUS *CLOUD FREE ONLY* SST ON ERTS-8 (2°K/250 METERS)
NIMBUS 5	MICROWAVE MAPPER	SEA SURFACE THERMAL FEATURES SEA ICE CONDITIONS	IMAGERY/DIGITAL	SPATIAL – 25 km	INDEPENDENT OF CLOUD COVER
NIMBUS G	OCEAN COLOR SPECTROMETER	WATER MASS CHLOROPHYLL POLLUTION	MULTICHANNEL IMAGERY	TO BE DETERMINED	MID-1970's
TIROS–N	ADVANCED VERY HIGH RESOLUTION RADIOMETER (AVHRR) DATA COLLECTION SYSTEM	SEA SURFACE TEMPERATURE SEA ICE BUOY/PLATFORM INTERROGATION	DIGITAL/IMAGERY	SPATIAL – 5 km ON A GLOBAL BASIS AND 1 km ON A LOCAL BASIS TEMP. – <1°C (rms)	LAUNCH 1977-1978
SEASAT	RADAR ALTIMETER MICROWAVE SCATTER-OMETER SYNTHETIC APERTURE RADAR MICROWAVE RADIOMETER VISIBLE/IR RADIOMETER	WAVE HEIGHT ALTITUDE WIND SPEED WIND DIRECTION WAVE SPECTRA IMAGES SEA TEMPERATURE (ALL WEATHER) SEA TEMPERATURE (CLEAR WEATHER)	1 – 20 METERS 4 – > 20 m/s 0 – 360° λ : 50 – 100 METERS σ : 0 – 360° 0 – 30°C -2 TO 35°C	± 10 cm TO + 100 cm ± 2 m/s OR 10% ± 20° ± 10% ± 10% 25 m RESOLUTION ± 1°C 1.5°C/7.5 km	1978 LAUNCH 2000 MILE SWATH
SKYLAB	*MULTI SPECTRAL PHOTOGRAPHY* INFRARED SPECTROMETER MULTISPECTRAL SCANNERS MICROWAVE RADIOMETER/SCATTEROMETER/ALTIMETER L BAND RADIOMETER	COASTAL FEATURES RADIANCE VALUES SEA STATE OCEAN PROFILING THERMAL RADIATION DEFLECTION FROM VERTICAL	IMAGERY 0.4 – 2.4 μm & 6.2 TO 15.5 μm 8 CHANNELS 4.4 μm TO 12.5 μm 19.3 GHz (2.2 cm) 1.46 GHz	FOV TO 100 METERS GROSS SST OVER 60 N. MILE CIRCLE	PROGRAMMED LIMITED EARTH SENSING MISSION COMPLETE MARCH 1979

Figure 2. Oceanographic Applications of Satellite Remote Sensors (Ref. 6)

	DOT	Navy	Army	NASA	NOAA	EPA	HEW	Interior	AEC	Acad Inst	Misc	TOTAL
Wave Height Sensor		62		25	12					15		114
Tide Gauge		36			573	3	8	3		59	47	729
Current Meter	26	315		7	167	55	3	4579[1]	1	602	192	5947
Salinometer	80	50		9	50	9	3	2	7	158	146	514
CTD, STD	42	33		12	88	1		2		31	56	265
Temperature Sensor[2]	9	603		32	203	7	1	41	1	783	46	1676
Reversing Thermometers	1387				700					1776	1414	5277
XBT Systems	24	531[3]			39					20		614[4]
Optical Instrument		30		16	4	13		3	1	34		101
Depth Sensor (Pressure)		49			27					37		113
Echo Sounder		104		1	151	5	1	94	4	130	3	493
Sound Velocimeter		50			4					7	12	73

[1] 4500 Price Gurley river flow meters.

[2] MTBs listed under temperature sensors.

[3] Includes 281 SXBT systems and 250 AXBT systems.

[4] Approximately 80,000 XBT's are deployed annually using these systems.

Figure 3. Oceanographic Instrumentation Inventory by Agency

IN-SITU INSTRUMENTS

• Interior	$	300K
• NOAA		650K
• Navy		500K
• Army		75K
• EPA		500K
• Academia		2,000K
TOTAL	$	4,025K

REMOTE MARINE SENSORS

• NASA	$	500K
• Coast Guard		1,550K
TOTAL	$	2,050K

Figure 4. FY-1975 Ocean Instrument Development

and organizations within the agency that were providing the funding and doing the actual development. It is this type of information that is one of the objectives of the present study.

Figure 5 summarizes oceanographic parameter measurement requirements vs the state-of-the-art. The required capabilities and 1974 state-of-the-art were taken from Ref. 6. The range of numbers under required capabilities reflect the requirements of a wide variety of uses. The 1977 state-of-the-art was obtained by a survey of data sheets from or telephone interviews with commercial manufacturers and the appropriate manufacturer is indicated. As can be seen, the state-of-the-art has improved significantly in the past three years in the measurement of the majority of the parameters.

2.3 CONCLUSIONS

Based on a review of previous survey and assessment studies and on discussions with individuals involved in the studies, it was concluded that the best approach to the survey work for NORDA's purpose would be to concentrate on measurement requirements and associated instrumentation needed to support ongoing Navy system-related programs. In particular, the needs of projects related to weapon and sensor system development and improvement would be emphasized as opposed to instrumentation needs for general oceanographic research which have traditionally received the majority of attention. It was also concluded that for any type of survey other than of the general oceanographic community, conducting personal interviews as opposed to a questionnaire survey, was the only effective approach.

The questionnaire of Fig. 6 was subsequently drawn-up as a working questionnaire to use during personal interviews with Navy project managers and other cognizant personnel. Although C., Environmental Data doesn't really address instrumentation directly, it is the data needs that ultimately drive the need for new or better instrumentation. It was felt that inclusion of this area might uncover data needs for which instrument development necessary to meet the needs had not yet been identified. This in fact

PARAMETER	REQUIRED CAPABILITIES Range and Accuracy	1974 CAPABILITIES Range and Accuracy	PRESENT CAPABILITIES (1977) Range and Accuracy	MANUFACTURER	TECHNIQUE A	B	C
Depth	0 to 6000 m ± (0.01% to 1%)	0 to 6000 m ± 0.25%	0 to 7000 m ± 0.01%	Plessey Environmental Systems	X		
Tides	0 to 20 m ± (0.1 cm to 2 cm)	0 to 20 m ± 1 m	0 to 30 m ± 0.03%	Montedoro-Whitney	X		
Wave Height	0 to 30 m ± (1 cm to 10%)	0 to 30 m ± 5%	0 to 20 m ± 0.03%	Montedoro-Whitney	X		
Wave Direction	0 to 360° ± 5°	0 to 360° ± 10°	Same	Environmental Devices Corp.	X		
Wave Period	1 to 40 sec ± 0.1 sec.	1 to 40 sec. ± 0.1 sec.	4 to 18 sec. ± 0.01%	Montedoro-Whitney	X		
Current Speed	0.5 to 260 cm/sec. ± 0.5 cm/sec.	1.5 to 260 cm/sec. ± 2.5 cm/sec.	5 mm/sec to 5 m/sec. ± 1%	Montedoro-Whitney	X		
Current Direction	0 to 360° ± (2° to 10°)	0 to 360° ± 3°	0 to 360° ± 2°	Montedoro-Whitney	X		
Temperature	-2 to 40°C ± (0.001 to 0.5°C)	-2 to 40°C ± 0.02°C	-5 to 50°C ± 0.001°C	Montedoro-Whitney	X		
Conductivity	0 to 70 mmho/cm ± (0.001 to 0.1 mmho/cm	0 to 70 mmho/cm ± 0.02 mmho/cm	0 to 65 mmho/cm ± 0.005 mmho/cm	InterOcean Systems	X		
Salinity	0 to 48 ppt ± (0.003 to 0.5 ppt)	0 to 48 ppt ± 0.05 ppt	0 to 45 ppt ± 0.02 ppt	InterOcean Systems	X		
Density	-1 to 30 σ_t ± 0.01 σ_t	10 to 30 σ_t ± 0.02 σ_t	Same	Hydro Products	X		
Light Penetration	10^{-6}-10^{4} lumens, 8000-4000 Å ± < 3%	10^{-5}-10^{4} lumens 8000-3000 Å ± 3%	0-1700 lumens 7500-3000 Å ± 1%	InterOcean Systems	X		
Light Beam Attenuation	0 to 100% ± < 2%, 8000-3000 Å ± < 0.2%	0 to 100% ± 2%, 8000-3000 Å ± 0.2%	0 to 100%, ± 1% 8000-3000 Å ± 0.1%	Montedoro-Whitney	X		
Sound Speed	1400 to 1700 m/sec. ± (0.02 to 1 m/sec.)	1400 to 1700 m/sec. ± 0.3 m/sec.	1400 to 1600 m/sec. ± 0.02 m/sec.	Ramsay Engineering	X		
Acoustic Transmission Loss	0.003 to 1.0 dB/m ± 0.00001 dB/m	0.003 to 1.0 dB/m ± 0.00001 dB/m	Same	Environmental Devices Corp.	X		
Ambient Noise	-15 to -80 dB ± 1 dB	-15 to -80 dB ± 1 dB	Same	Environmental Devices Corp.	X		

TECHNIQUE:
A — Measurement can be made in-situ
B — Measurement can be made in field station
C — Measurement must be made in laboratory

Figure 5. Oceanographic Parameter Measurement Requirements vs State-of-the-Art

A. INSTRUMENTATION IMPROVEMENT

What specific instruments need to be improved and what are the required improvements in the three areas below? Give reasons for or application of improvement.

1. Performance Characteristics — Measurement capabilities such as range, accuracy, resolution, time/frequency, response, etc.

2. Operational Characteristics — Operational limitations and conditions such as tow speed, sea state, in-situ capability, automation of data recording, real time processing and ease of deployment.

3. Logistics Characteristics — Considerations such as initial cost, ease and cost of maintenance, repair and calibration, and auxiliary equipment such as winches, cables, etc.

Consider both individual sensors and complete measurement systems with one or more sensors such as STD's, towed platforms, etc.

B. NEW INSTRUMENTATION DEVELOPMENT

What new instrumentation needs to be developed and for what specific purposes?

Consider the following two areas:

1. Long Term Monitoring — Instruments such as data buoys and satellite remote sensors.

2. Short Term Surveying — Instruments such as aircraft deployable/recoverable buoys, aircraft remote sensors, ship towed multi-sensor platforms, portable ship-deployed instrument packages.

C. ENVIRONMENTAL DATA

What types of environmental data need to be collected and what experiments are required to get this data? Give reasons for need and amount of data required.

Figure 6. Questionnaire on Oceanographic Instrumentation R&D Needs

turned out to be the case. This questionnaire proved to be quite useful both in conducting interviews and in categorizing needs which were identified during the interviews. The results of these interviews are presented in the next section.

Section 3

SURVEY OF NAVY MEASUREMENT REQUIREMENTS AND INSTRUMENTATION DEVELOPMENT

3.1 APPROACH

As mentioned in the previous section, the scope of the requirements survey was limited to measurement requirements and associated instrumentation needed to support ongoing Navy programs related to sensor and weapon systems. It was necessary to limit the scope in some manner since a survey of the needs of the entire oceanographic community, even within the Navy would require a much larger effort than this study could support. In addition, oceanographic instrumentation development in support of sensor and weapon systems has received less attention than more general instrumentation, primarily because it is more specialized and the details of the application are often classified.

As a result of limiting the scope of the requirements survey in this manner, it was sufficient to limit the survey of instrumentation development primarily to Navy sponsored work, except in a few cases where the need was for an instrument that would also be of general use to the civilian community. As can be seen from Figs. 3 and 4, the Navy's use and development of marine instrumentation (which includes part of that listed under academia) is only a fraction of the total community and a survey that included all users would be a major undertaking. Fortunately, most individuals involved in instrumentation development funded by the Navy are also aware of similar development work in other sectors of the oceanographic community so that one can get a good idea of what is being done in any given area of instrumentation development without having to survey the entire community. The results of the NOAA and Coast Guard surveys mentioned in Sec. 2.2 should supplement the results of this survey in this area.

Within the scope of the survey as defined above, there were a number of possible approaches to organizing the conduct of the survey and the presentation of the results. The approach taken was basically two-fold. First, appropriate program and project managers in the various Navy management organizations were contacted in order to discuss the projects under their cognizance. Organizations included NAVMAT, NAVSEA, NAVAIR, NAVELEX and ONR plus ARPA. As might be expected, "appropriate" managers were primarily those involved in the development of weapons and surveillance systems for acoustic and non-acoustic ASW. Second, several laboratories were visited to either discuss in more detail projects identified above or to find out what relevant work was being done under in-house R&D funds. Laboratories visited included NUSC/New London, NUSC/Newport, NRL and APL/Johns Hopkins University.

In selecting program managers and laboratories to visit, one of the guidelines used was to concentrate on programs with which NORDA might not be familiar in keeping with the original objectives of the survey. In addition, sufficient information was obtained from program managers in many cases that it was not felt necessary to visit or contact the laboratory or institution performing the work. Consequently, the exclusion of a laboratory or institution from this report is in no way an indication of the importance of its programs.

The following section presents the results of telephone or personal interviews with the various organizations and laboratories.

3.2 SURVEY RESULTS

Results are presented as information gathered during interviews and include both measurement and instrumentation requirements, and instrumentation development work. In general, information which was not relevant to the purpose of the survey has not been included. Thus this section is not intended as a summary of programs in which the various organizations contacted are

involved but rather a summary of instrumentation and measurement problems encountered and relevant developmental work toward solving those problems. Names of individuals given include both people who were interviewed and people who are cognizant of the indicated areas as further points of contact.

NOAA OFFICE OF MARINE TECHNOLOGY, TEST AND EVALUATION LABORATORY

Eugene Russin, Chief, Sensor Test Branch

NOAA's T&E Laboratory is essentially the former NOIC. As such, many instruments under development are brought here for calibration and evaluation. The following was ascertained:

- It was felt that the greatest need in general purpose oceanographic instrumentation was for a more reliable current meter. Fouling is still a major problem with mechanical types. Although EM types have been around for a while, they are quite sensitive to housing design effects on flow in the sensor area. A new design by Jack Olson at NOSC was recently evaluated and appears promising. More development work needs to be done with acoustic current meters and possible optical techniques as well. A Neil Brown Mark III CM was being tested at the time of the visit.
- Another area that needs better instrumentation is the water quality area. Specifics were not discussed.
- R. W. Austin at Scripps is preparing an optical instrumentation handbook for NOAA. Draft is due 1 September.
- This laboratory is doing a study of current sensors and open ocean (rider type) wave sensors. Study will include effects of motion on performance and a state-of-the-art summary of both off-the-shelf and developmental instruments.

OFFICE OF NAVAL RESEARCH

Persons Contacted and Area of Interest:

Dr. Al Sykes	—	Ocean measurements to support acoustic systems
Dr. Dave Lewis	—	Optics
Dr. Matt White	—	Ocean Optics

Instrumentation/measurement needs indicated were:

- Time series of vertical temperature profiles for detecting internal waves. An XBT profile every 10 minutes would suffice but the XBT's would have to be cheaper and have better resolution than present units.
- A profiling current meter would be very useful for measurements of current shear.
- A small, in-situ, digital recording package for acoustic data acquisition. Present analog recorders are a waste of bandwidth in most applications. Digital recording would increase the data capacity of an unattended sensor.
- An array of wave sensors for prediction of acoustic surface reverberation. Sea state alone is insufficient. Time and spatial correlation lengths are needed.
- Optical communications with submarines from aircraft or satellites requires measurement of ocean optical properties. Although ship deployable instrumentation exists, air deployable devices would be superior for rapid survey or for tactical useage. None exist at present nor does any development appear to be going on in this area.

DEFENSE ADVANCED RESEARCH PROJECTS AGENCY

Persons Contacted:

Dr. Phil Selwyn — Ocean Monitoring and Control Division, Tactical Technology Office

DARPA is interested in non-acoustic ASW, among other things, and is funding some studies in this area. Of particular interest are internal waves and associated turbulence generated by current shear-induced instabilities. Instrumentation studies being funded include:

- Development of an acoustic vorticity meter. It is felt that vorticity may be a better measure of internal waves than vertical motion. In addition, it is not affected by translational motion and could be mounted on a towed platform or a submarine.
- Laser Doppler Velocimeter (LDV) Studies. This is the ultimate local velocity sensor if it can be made workable in the ocean because it allows one to get out of the flow field of the platform.

With regard to both acoustic and laser velocimeters, it is felt that the question of whether or not the acoustical and optical scatterers are truly neutrally buoyant and follow the water motion has not yet been answered.

Instrument needs expressed were:

- Stabilized thermistor chain. There are several excellent thermistor chains around but platform motion corrupts the data taken.
- Current shear meter. Shear measurements are needed to determine the Richardson number.

NAVAL MATERIAL COMMAND

MAT 0314 — Program Administrator for Undersea Surveillance, CDR Keith Hastie

The Undersea Target Surveillance program element is a 6.2 program in detection of undersea targets such as submarines, mines and swimmers. CDR Hastie felt that the only work of interest to NORDA was the PANOIC experiment being conducted in the Pacific as a joint effort of NAVOCEANO, ARPA and ONR (Code 222) with support from this program element. It was suggested that the Ocean and Atmospheric Support program element would be more relevant to NORDA's interests. Since NORDA is quite familiar with this program, this was not pursued.

NAVAL ELECTRONICS SYSTEMS COMMAND

ELEX 320	—	Undersea Surveillance Division

Persons Contacted:

CDR Al Miller	—	Code 320
Bill Kamminga	—	Code 3202, Technical Assistant for Ocean Sciences Programs

ELEX 320 works closely with PME-124, the Undersea Surveillance Project, to develop an understanding of acoustic propagation as it relates to the performance of acoustic surveillance systems including bottom mounted, towed, and air-deployed arrays. On-going projects are mainly concerned with acoustic measurements and instrumentation needs are minimal. Although non-acoustic surveillance comes under the domain of 320, there is presently no work being supported in this area.

NAVAL SEA SYSTEMS COMMAND

SEA 03E — Oceanographer and Environmental Assistant, John Ropek

SEA 03E's primary interest is in environmental measurements related to prediction of torpedo performance. Measurement/instrumentation needs expressed were:

- An expendable sound velocimeter would be much preferred over predicting SV profiles from BT's. Salinity structure in the ocean is more important than previously thought.
- Means of predicting acoustic surface reverberation without having to use active sonar. Sea state information is not enough. An optical or some other technique is needed to measure the surface wave spectrum from a submarine.
- Current profiles are needed to predict acoustic doppler shift vs depth. A submarine-launched profiler is needed for the MK 48 and an air-launched one for the MK 46.
- BT is most important measurement needed at present. Finer structure BT's may be needed in the future.
- Operating forecasting of turbulence is seen as a possible future need.

SEA 06H2 — Advanced Systems and Integration Office, LCDR Dave Bolka

The feeling was expressed that instrumentation and measurements needed to support acoustic systems were by-and-large satisfactory. An instrument that would be convenient would be an expendable sound velocimeter (XSV) although for most purposes, SV profiles as presently derived from BT's are sufficient.

NAVAL AIR SYSTEMS COMMAND

AIR 370 — Surveillance Administration

Persons Contacted:

Barry Dillon — Code 370E, Non-Acoustic Sensor Surveillance

The only need for instrumentation to support non-acoustic detection systems in the air community is for an expendable, air-deployable k-meter to measure the diffuse optical attenuation coefficient, k, of seawater. This measurement is needed to predict the performance of the ORICS (Optical Ranging, IFF, and Communication System) system, which uses a blue-green laser for subsurface detection and communication.

As far as instrumentation to support acoustic and underwater weapon systems are concerned, AIR 370C is chartered to, and is involved in the development of systems to predict performance as influenced by natural environmental conditions. Basically, their job is similar to NORDA's but for the air community specifically. Present efforts are aimed at improving air XBT's and developing dropsondes and other instrumentation to predict atmospheric effects on microwave and optical propagation.

SSBN Security Program

The SSBN Security Program at APL is concerned with submarine detectability in all areas of acoustics and non-acoustics. The most relevant area of interest to NORDA is Applied Hydrodynamic Program. This program is concerned with the possible effects of turbulence and internal waves generated by a submarine and has conducted a number of at-sea measurement tests with and without submarines. Oceanographic instrumentation suitable for measurement of turbulence and internal waves is virtually non-existent commercially and a large part of the effort in this program is defining and developing instrumentation and techniques for measuring the phenomena.

Cognizant individuals in the Applied Hydrodynamics Program are:

Dr. Larry Crawford	—	Program manager
Dr. Carl Gundersdorf	—	Towed thermistor/fluorometer chain
Dr. Dave Johnson	—	Turbulence measurements
Dr. Dave Wendstrand	—	Internal waves

Instrumentation/measurement needs include:

- Small-scale measurements of temperature and salinity. These require fast response sensors and a stable platform for towed measurements.
- Measurements of current shear for determination of Richardson numbers. Development of an acoustic velocimeter is being supported for this purpose.
- Small-scale velocity fluctuations. LDV's and Acoustic DV's are potential solutions but no satisfactory instrument exists for ocean use. APL is investigating the use of these as well as cold films and other sensors.

NAVAL UNDERWATER SYSTEMS CENTER, New London

Persons Contacted:

Dr. Bill Von Winkle	—	Associate Technical Director for Technology, Code 10
Ray Hasse	—	Head, Special Projects Department, Code 31
Tom Cummins	—	Head, Ocean Technology Division, Code 311
Dr. Peter Cable	—	Head, Advanced Systems Technology Division, Code 313
Ralph Polley	—	Head, Submarine Electro-Optics Systems Division, Code 343
Dr. Bill Stachnick	—	Courageous Project, Optics, Code 343
Charles Veitch (MAR, Inc.)	—	SEAGUARD Project

Instrumentation/measurement needs expressed and relevant development work include:

- Preprocessing of acoustic data from multi-element arrays is needed to reduce telemetry bandwidth requirements and size of cables. This is a good application for microporcessors.
- It would be very desirable to have a 5000-7000 foot towed hydrophone array with a diameter of 5/8" and on the order of 400 hydrophones. Fiber optical telemetry provides a solution to size, weight and bandwidth problems provided a compatible hydrophone can be developed. NUSC, Code 313, as well as at least two commercial companies have been working on the development of an optical hydrophone, i.e.,

an acousto-optic transducer, that would interface directly with fiber optics and should also be smaller and cheaper.

- Ship and air deployed arrays need to be lighter. Application for fiber optics and Kevlar.

- A small heading sensor is needed that will fit into a thin array for passive measurements of array shape. Size needed is $\approx$ 1.9 cm x 10.2 cm (3/4" x 4"); accuracy, $1/4^{\circ}$-1°. Such a sensor is applicable to SEAGUARD, SASS and Thinline programs.

- Small tension cells are needed to measure forces acting on towed or vertical arrays.

- A good differential pressure gauge that can operate in deep ($\approx$ 5500 m) water is needed for accurate measurements of vertical angles of arrays.

- NUSC is involved in boundary layer turbulence measurements near the bottom to investigate transport of waste from dredge disposal sites. A good means of measuring turbulence is needed. Conventional current meters are not really designed for this.

NAVAL UNDERWATER SYSTEMS CENTER, Newport

Persons Contacted:

John D'Albora	—	Code 36313, Courageous Project Manager
Dr. Ken Kemp	—	Code 36313
Dr. Guido Garosi	—	Code 36313
Dr. Dave Shonting	—	Code 311
Gerald Cook	—	Code 311
Dr. Don Connors	—	Code 311

The Courageous Project is involved in the measurement of turbulence and the associated effect on the T,S microstructure in the ocean. Measurements needed for which instrumentation is not commercially available include:

- Small scale measurements of T and S. Small scale is defined as 100 m down to centimeter or possibly millimeter scales. Platform stability, sensor size and sensor time response are problems at small scales. Exact number for smallest scale needed is difficult to estimate since not enough is known about such T,S structure at such scales to assess its importance. Carl Gibson at Scripps has been developing a microscale CTD which may be useful for such measurements.
- Measurements of current shear on the order of 1 cm/s in 1 m i.e., 10^{-2} /s are needed to calculate Richardson numbers. The Richardson number is needed to predict turbulence generated by internal wave instabilities.
- Measurements of current (velocity) fluctuations. A large part of the Courageous Project has been the investigation of instrumentation to make the above measurements. A number of instruments and sensors have been investigated. Observations

made thus far are:

- Acoustic current meters need to be improved in sensitivity and resolution. In addition, a better understanding of the acoustic scattering coefficient of seawater is needed.
- Laser Doppler Velocimeters such as the DISA LDV current meter are potentially quite useful but need improvement.
- A hot film anemometer for ocean use would be highly desirable.
- Pressure sensors have been used by NUSC for some time as a means of sensing the mean and fluctuating components of the water velocity. The operating principle is the same as that of a pitot tube except that the interpretation of the response to a time dependent velocity has been open to question. This technique may be useful for shear measurements, depending on the sensitivity.
- Regardless of how good a sensor one has, platform stability is paramount when making microstructure or current measurements. NUSC has been developing a towed device for making these measurements but it needs more work.

NAVAL RESEARCH LABORATORY

Persons Contacted:

Dr. Joe Elliot	—	Associate Superintendent for Ocean Science Applications, Code 8301
Gene Rudd	—	Applied Oceanography, Code 8310

NRL has been involved in non-acoustic ASW studies for some time. Work still on-going includes bioluminescence studies, gas measurements, and hydrodynamic studies. The hydrodynamic studies appear to have the greatest measurement instrumentation needs of interest to NORDA. These include:

- Expendable profiler for measurement of current shear, temperature and salinity. These three quantities provide the Richardson number. It is felt that the performance of salinity profilers is not yet acceptable and needs more development work.
- Directional spectra of internal waves. Internal wave amplitudes can be as large as 10 m or more and consequently the vertical displacement of the sound velocity profile can have a significant effect on acoustic propagation. NRL has used temperature chains in the past to make such measurements.
- Current shear has also been found to affect acoustic propagation. Current profiles are needed for this purpose as well as for Richardson number determination.

NRL is presently surveying available instrumentation and techniques for measuring current and T,S profiles. They expect to complete the survey sometime in September and will then decide on the best instrumentation to support for use in their studies.

3.3 CONCLUSIONS

Based on the approach taken to the survey and the experience during the survey, several conclusions have been drawn regarding the effectiveness of the survey:

- The identification of measurement and instrumentation needs by talking to program/project managers in the various program management organizations is most effective for projects at the 6.3 or higher stage in RDT&E which are identified as line item projects.
- Requirements of projects in 6.1 and 6.2 are more difficult to identify at the program administrator level and generally require contacting the performing laboratory or contractor. In addition, these requirements are less "firm" than those of projects in more advanced stages.
- Instrumentation development in support of 6.2 projects is also more difficult to identify without dealing with the performing organization.
- Fortunately, individuals who are involved in instrumentation development are usually aware of similar development efforts elsewhere, and after contacting a few knowledgeable people in a given area of instrumentation, one can be fairly certain that the field has been covered.

While it is difficult to tell how complete a survey has been, and the present one was not intended to be all-inclusive, a number of instrumentation needs have been uncovered which are of potential interest to NORDA. These are summarized in the next section.

Section 4

SUMMARY

This section summarizes instrumentation and measurement needs identified during the survey and discussed in Sec. 3.2. The needs are listed in order determined by: (1) the number of different projects indicating the need, (2) significance of the availability of the instrument or measurement capability to the success of the project and (3) significance of the project to the overall performance of a weapon or sensor system. While these judgements and their relative weighting are certainly subjective, they are the judgement of the authors based on information and impressions gathered during the interviews.

Oceanographic instrumentation and measurement capabilities needed by the Navy community to support ongoing projects related to weapon and sensor systems include:

- An expendable current profiler both for ship and air deployment. The need for such an instrument was identified in several projects for both acoustic and non-acoustic applications. Acoustic application is for prediction of doppler shift change and its effect on propagation. Non-acoustic application is for measurement of current shear which is needed to determine the Richardson number, a measure of the ability of internal waves to generate turbulence through shear-induced instabilities. NORDA is presently supporting the development of such an instrument and should continue to do so.

- Acoustic or laser doppler velocimeter with a remote sensing (outside of flow perturbations) capability. Such an instrument could be used to measure current shear, vorticity, and turbulence as well as mean flow and would find a large number of users and applications.

- An expendable sound velocity profiler or T,S profiler. For acoustic SV profiles, either device would suffice and both ship and air-deployable versions are desirable. For non-acoustic applications, a T,S profiler is desired for rapid measurement of density profiles to determine the Brunt-Vaisala frequency and, in conjunction with current shear, the Richardson number profile.

- Microscale measurements of T,S and v for detection of turbulence and the mixing effects of turbulence. Basically, this calls for small T,S and v sensors with high frequency response. The latter requires development of sensors such as acoustic/laser velocimeters, hot film sensors for ocean use or pitot-tube principle velocity sensors. Velocity resolution needs to be quite good for use on a moving platform.

- Current shear measurements from a moving platform such as a towed device or a submarine. Such a measurement capability requires very good velocity resolution and consequently the development of velocity sensors of the type mentioned above.

- An expendable, air-deployable optical k-meter. Measurements of the diffuse attenuation coefficient, k, are needed to predict the performance of air-to-subsurface optical detection and optical communication systems. In addition, measurements of the effective diffuse water backscatter reflectance ρ_w as well as depth profiles of ρ_w and α, the beam attenuation coefficient, are important in certain optical detection applications.

- <u>A small, fiber optic compatible hydrophone</u> should be developed. Fiber optics in moored, towed and portable arrays is inevitable and a compatible sensor will be required.

Other needs expressed include:

- A small heading sensor for thin arrays.
- A small, in-situ, digital recording package for acoustic data acquisition.
- Method of predicting surface reverberation from a submarine other than active sonar.
- A deep water differential pressure gauge for vertical array angle determination.
- Small in-line tension cells for towed and vertical arrays.
- Use of fiber optics to make towed and portable arrays lighter without sacrificing bandwidth.
- Use of in-situ microprocessors for preprocessing of acoustic data to reduce bandwidth and storage requirements.

Section 5

CONCLUSIONS AND RECOMMENDATIONS

In the course of the present survey, a number of both general and specific instrumentation and measurement needs were identified and were summarized in the previous section. The majority of these needs can be grouped into eight general measurement categories: current velocity, turbulence, sound velocity, temperature, salinity, optical properties, surface wave spectrum, and internal wave spectrum. In addition, seven specific improvements have been identified which deal with acoustic arrays.

Measurements in each of the eight general categories discussed below have wide-spread applicability and the development or support of the needed instrumentation should be considered by NORDA.

- Current Velocity

  The vertical profile of current velocity is needed within both the Navy and the general oceanographic community. Navy applications include acoustic propagation prediction and prediction of turbulence. The general oceanographic community requires this measurement in many phases of its work including pollution regulation, monitoring, acquisition of baseline data, and basic research.

  The development of almost any reliable current profiler is desirable and is recommended. However, an expendable, air/ship deployable profiler is preferred and would find application by many users. The desirability of this measurement is indicated both by discussion with Navy personnel and by the number of individual instruments undergoing development in the private sector, such as the Cyclesonde

at the University of Miami and the Drop-Sonde at Woods Hole.

In addition to a current profiler, a "differential" current meter should be developed to allow measurements of current shear from a moving platform. Techniques employing matched conventional current meters have been used in the past but have been unsatisfactory, largely due to insufficient velocity resolution. Candidate sensors include those applicable to turbulence measurement.

- Turbulence

The ability to accurately measure turbulence (velocity fluctuations) is highly desired within both the Navy and the general oceanographic community. As with a current profiler, users outside the Navy would include regulatory and monitoring agencies on Federal and State levels, and basic researchers. Although highly specialized delicate instruments such as hot film flowmeters have been developed by researchers in the past, it is desirable to develop either an acoustic or laser doppler velocimeter for ocean use since hot films, hot wires, etc., are beset by fouling problems. LVDs exist for use in flow channels in laboratories but development is required to allow them to be used in the ocean environment. The use of pressure sensors for turbulence measurements should also be investigated.

- Sound Velocity

Knowledge of the sound velocity profile is the most basic measurement need of the Navy. Although instruments to measure sound velocity directly exist, an expendable, air/ship deployable SV profiler would be

a useful instrument if it could be manufactured cheaply enough. The adequacy of SV profiles derived from BT's needs to be investigated in detail to determine the actual degree of need for an expendable SV profiler.

- <u>Temperature</u>

  Vertical profiles of temperature on a large scale are used for calculating sound velocity profiles and Brunt-Vaisala frequency profiles and instrumentation for such measurements is by-and-large satisfactory. Horizontal and vertical profiles of temperature on microscales (few cms) are needed for detection studies and require physically small sensors with short thermal time constants. A fair amount of work is going on in microscale temperature sensors and the only involvement by NORDA is seen as a possible future need for a microscale XBT.

- <u>Salinity</u>

  The addition of a conductivity sensor to an XBT is needed for two purposes. The first is for the calculation of density profiles from the large scale T, S profile and possibly for microscale measurements of salinity. The second is the need for profiles of both T and S in the calculation of the sound velocity profile in ocean areas where salinity fluctuates significantly about its seasonal mean. Although there is presently no operational need for density profiles, it is quite likely that there will be in the future as is now the case for sound velocity profiles. For the latter measurement, a cost/accuracy trade-off study needs to be performed

to determine the desirability of T vs T, S vs direct SV profiles. In any case, the integration of a conductivity sensor into an XBT should be pursued.

- Optical Properties

  Navy air-to-subsurface optical communication and detection systems require data on the diffuse and beam attenuation coefficients and the diffuse backscatter reflectance vs depth. Although there are currently no such systems beyond the 6.2 stage of RDT&E, efforts are increasing in these areas in both the ASW and SSBN security communities. While no operational need currently exists for such measurements, there is a need for a rapid survey capability in operational ocean areas as well as a need for optical measurements during at-sea testing of developmental systems.

  While instrumentation exists to make such measurements from ships, the development of air-deployable instrumentation would be a real boon to a number of programs in terms of both cost of ship operations and a much more rapid survey capability. The general oceanographic community, and in particular the water quality quarter, would also find considerable use in such instrumentation.

- Surface Wave Spectrum

  An operational need exists to predict acoustic surface reverberation from a submarine without having to use its active sonar. A submerged submarine's present knowledge of the sea surface condition is inadequate for such predictions. A submarine deployable wave sensor is needed with the capability of measuring the sea surface wave spectrum as applicable to acoustic

reverberation. The specific characteristics required of such a wave sensor need to be investigated.

- Internal Wave Spectrum

  The measurement of internal waves is important to a number of ongoing Navy programs involved in hydrodynamic detection studies. Measurement of internal waves is generally done indirectly by measuring the displacement of the temperature, salinity or turbidity structure of the ocean and instrumentation for such measurements is by-and-large satisfactory. Direct measurement of water velocities requires very sensitive current sensors. While the sensitivity of state-of-the-art acoustic and EM current meters is quite good, the development of an LDV for ocean use, particularly one with a remote, volume scanning capability, would be very welcome in the internal wave community and would allow measurement capabilities which are difficult if not impossible at present. In particular a scanning LDV with good sensitivity and resolution would allow measurements from moving platforms of small currents, current shear and vorticity. Development of an LDV for ocean use should be given a high priority because of its many potential applications.

The specific developments needed in the area of acoustic arrays are:

- Acousto-Optic Hydrophone
- Lighter weight arrays
- Small heading sensor
- Small in-situ, digital recorder
- Deep water, differential pressure gauge

- Small tension cells
- Preprocessing of data

Although these developments are of less interest to the general oceanographic community than those just discussed, fixed and towed arrays are, and probably will remain, the primary ASW sensor due to the nature of the underwater medium. Advancement in the state-of-the art of acoustic array technology will depend on the above developments as well as developments in array fabrication employing new materials such as Kevlar. The above development seen as having the most significant impact on array technology is the incorporation of fiber optics for telemetry which will require a compatible hydrophone. Although development of an acousto-optic hydrophone has been going on for the past several years, a much greater effort is needed.

Table 7 summarizes and prioritizes the conclusions and recommendations presented in this section. An attempt has also been made to estimate the required accuracy or resolution where this was possible. In many cases, it is difficult to put a number on a requirement because not enough is presently known about the parameter of interest in the ocean, particularly at small physical scales. Other characteristics required of new or improved instrumentation are also listed as appropriate.

To summarize, a number of instrumentation and measurement needs have been identified which are not being met by currently available instrumentation. In a number of cases, development work is currently in progress on such instrumentation but needs emphasis and/or additional support. In other cases, development of instrumentation is inadequate or non-existent as far as could be determined. Before any new development support is initiated by NORDA, this assumption should be investigated more closely.

Instrumentation Development Needs	Probable Users	Priority	Instrument Characteristics
Current Velocity	Navy and Others	1	Expendable profiler; $\pm$ 1 cm/s in 1m resolution
Current Velocity	Mostly Navy	1	Current shear from moving platform; same resolution
Turbulence	Navy and Others	1	$\pm$ 0.01 cm/s resolution on cm scale
Sound Velocity	Mostly Navy	1	Expendable profiler; $\pm$ 0.1 m/s accuracy on m scale
Temperature	Navy and Others	2	μ-scale profiler; $\pm$ 0.001^{o}C resolution on cm scale
Salinity	Navy and Others	1	Addition to XBT; $\pm$ 0.1 ppt accuracy on m scale
Salinity	Navy and Others	2	μ-scale profiler; $\pm$ 0.001 ppt resolution on cm scale
Optical Properties	Navy and Others	2	Expendable profiler; $\pm$ 5% accuracy on m scale
Surface Wave Spectrum	Mostly Navy	3	Submarine deployable
Internal Wave Spectrum	Navy and Others	2	Scanning LDV
Acousto-Optic Hydrophone	Navy	2	1.5 cm diameter; same sensitivity as conventional hydrophones
Lighter Arrays	Navy	2	Fiber optic telemetry
Small heading Sensor	Navy and Others	3	2 cm diameter; $\pm$ .25^{o} resolution
Small Digital Recorder	Navy and Others	3	
Differential Pressure Gauge	Navy	3	
Small Tension Cells	Navy	3	
Preprocessing of Acoustic Data	Navy	3	Microprocessors

Figure 7. Summary and Recommendations

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